Clock Noise Removal in LISA

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Contributors:
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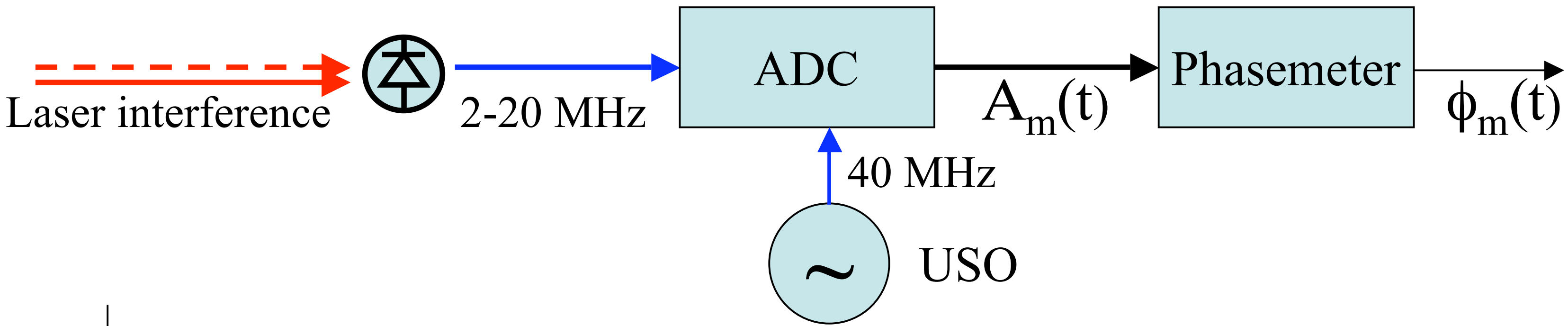
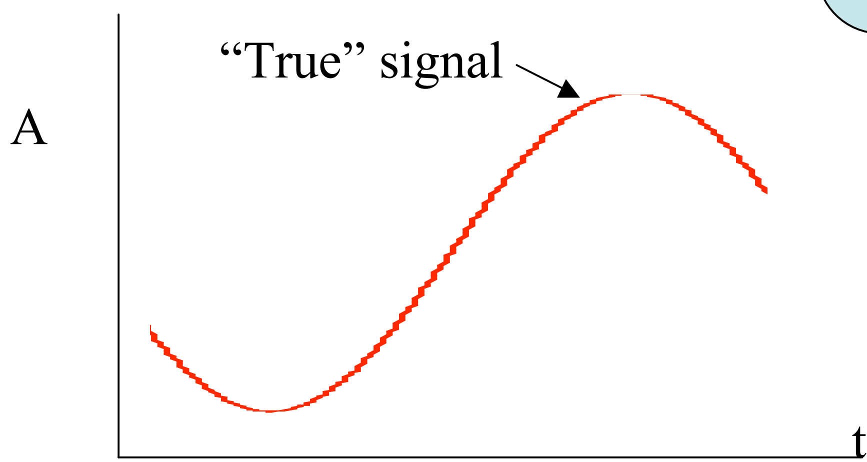
- Clock noise introduces errors into the LISA phase measurement
- Existing clocks are not stable enough to meet the LISA requirement
- A scheme exists for transferring the clock noise between spacecraft optically in order to measure and correct for it
- A commercial phase modulator represents the clock noise adequately for a modulation frequency of 8 GHz

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Clock? What Clock?

- Science observables are phase measurements of heterodyne beatnotes between lasers.
- Phase measurements are relative to the clock (USO) that drives the analog-to-digital converter (front end of phasemeter):





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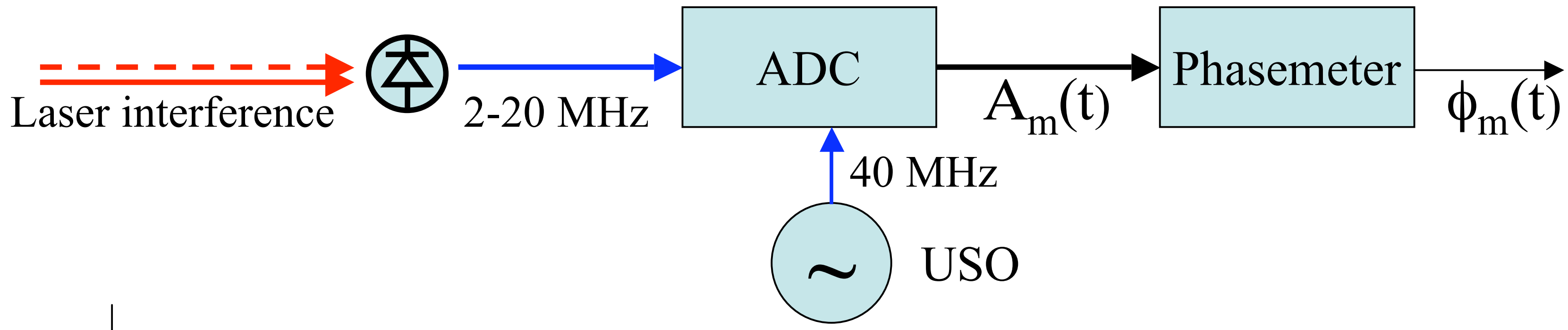

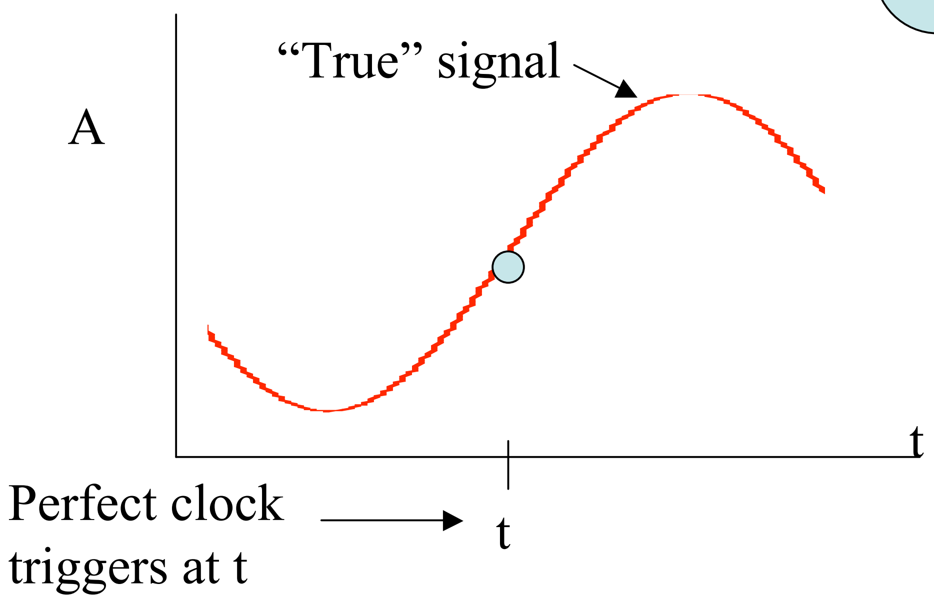

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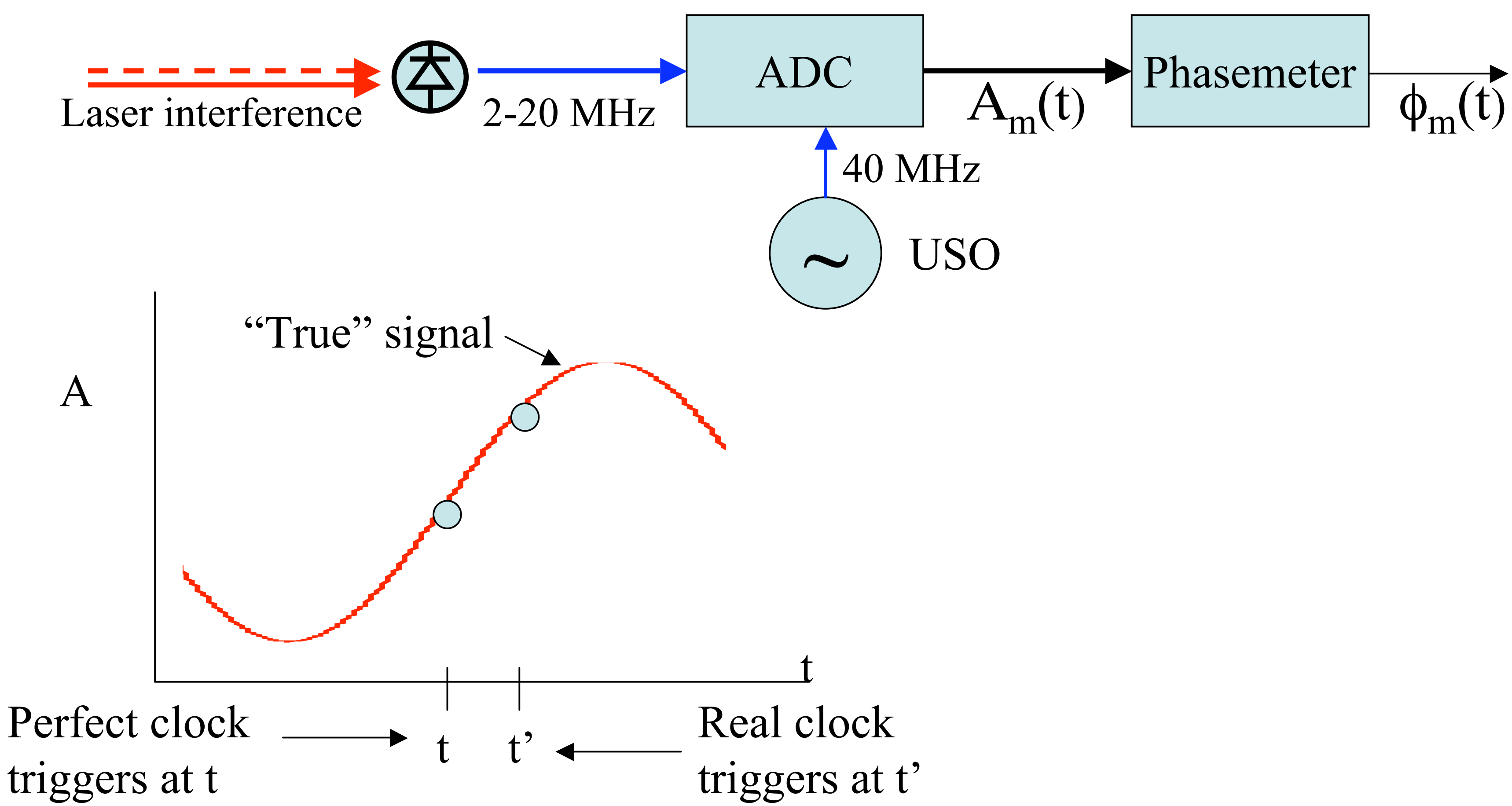

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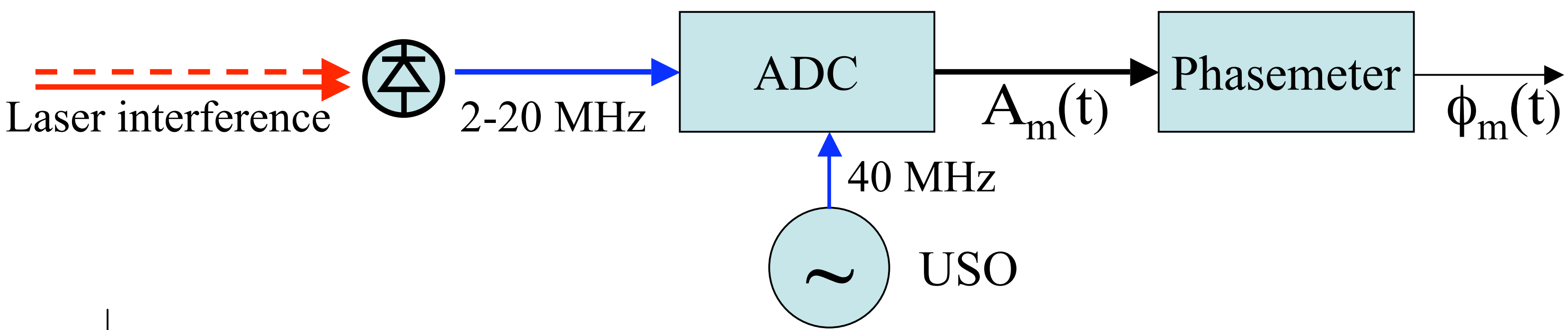
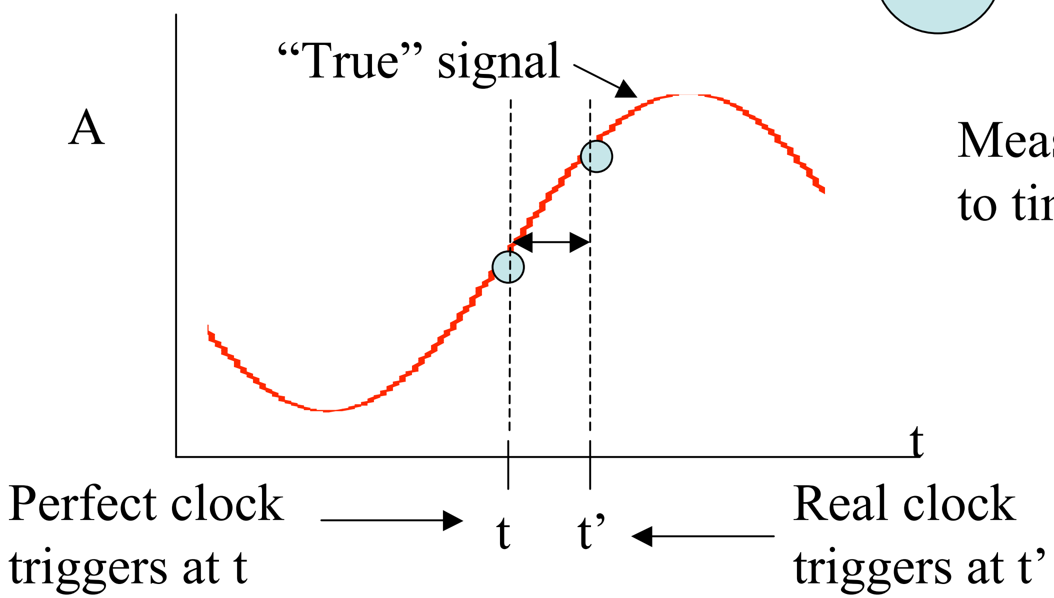


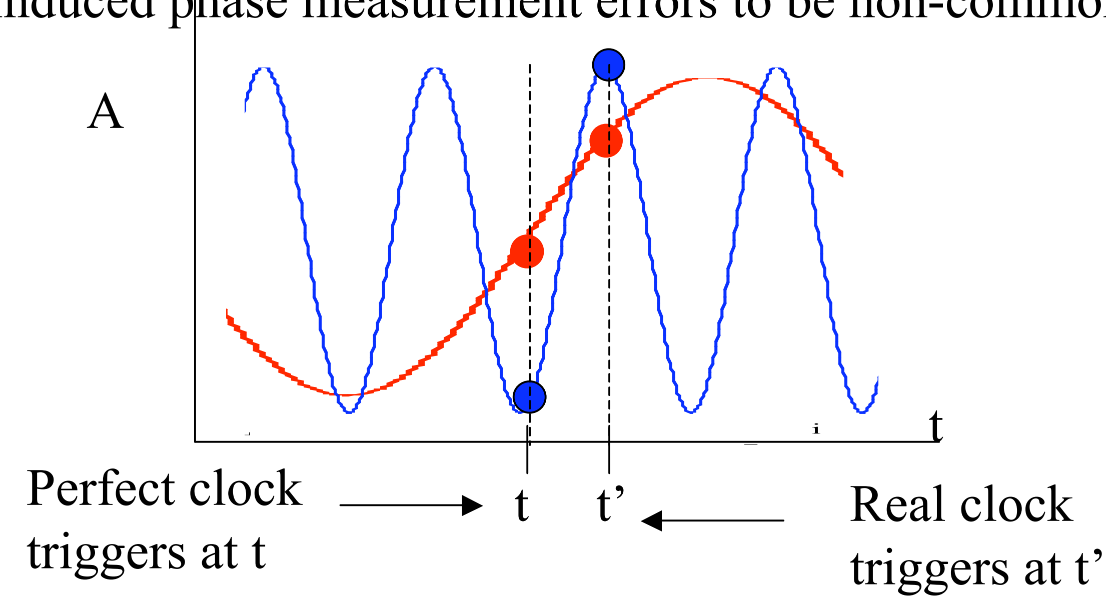


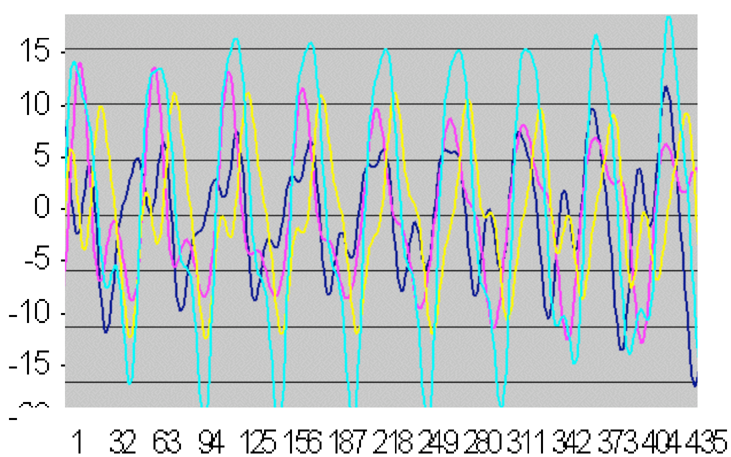
Measured phase has error due to timing error

Doppler shifts introduce clock noise

Residual spacecraft velocity results in multiple heterodyne frequencies

¬ causes clock-induced phase measurement errors to be non-common:



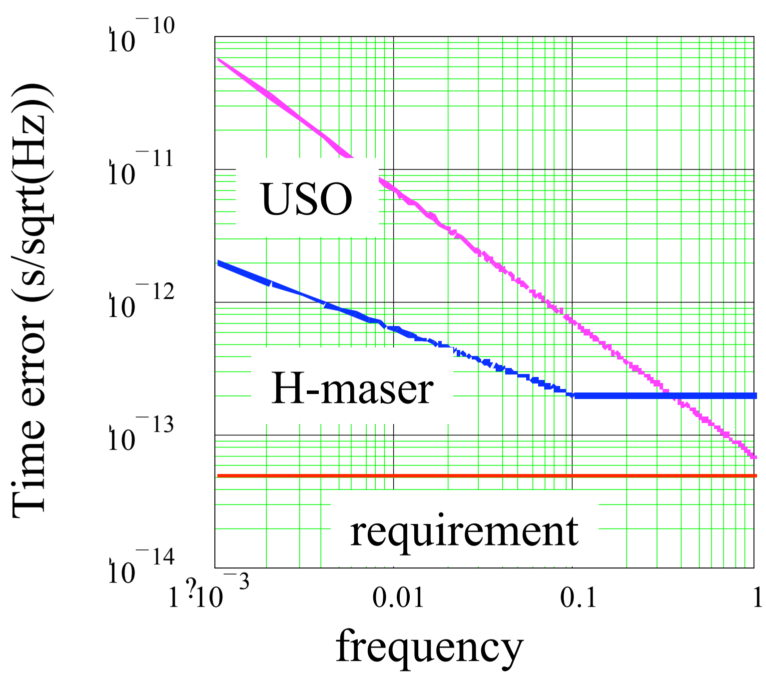


Residual spacecraft relative motion results in heterodyne frequencies changing between +/- 20 MHz

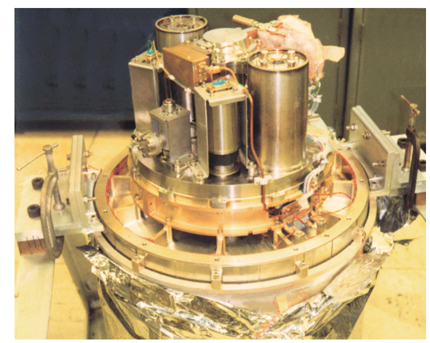
How good is good enough?

Errors in the phase measurement are specified to be ~ 10^{-6} cycle/√Hz

- The period of the 20 MHz heterodyne signal is 50 ns
- 10^{-6} /√Hz of this period is 50 fs /√Hz



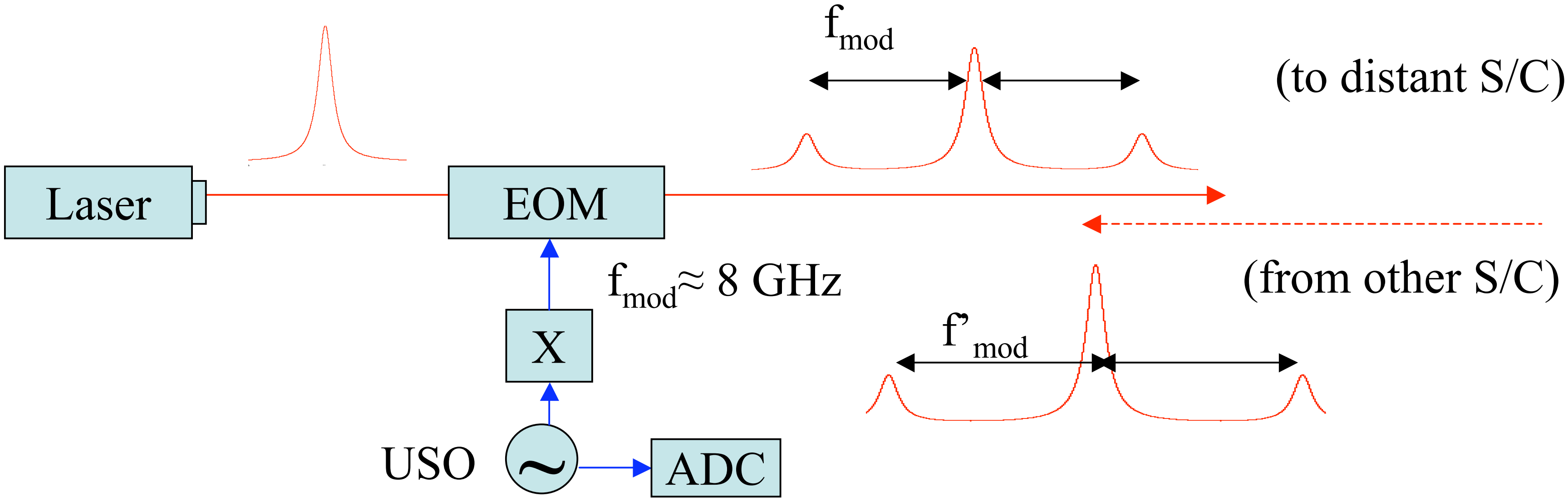
Symmetricom USO



SAO Space H-Maser

BUT: We don't need the clock to be that quiet, we just need to know what the difference in the clocks was, SO

Optical transfer of clock noise



The phase noise which we want to measure is enhanced by the ratio of f_{mod}/f_{het}

(relaxing requirements on RF-optical phase stability, shot noise on clock tone, etc)

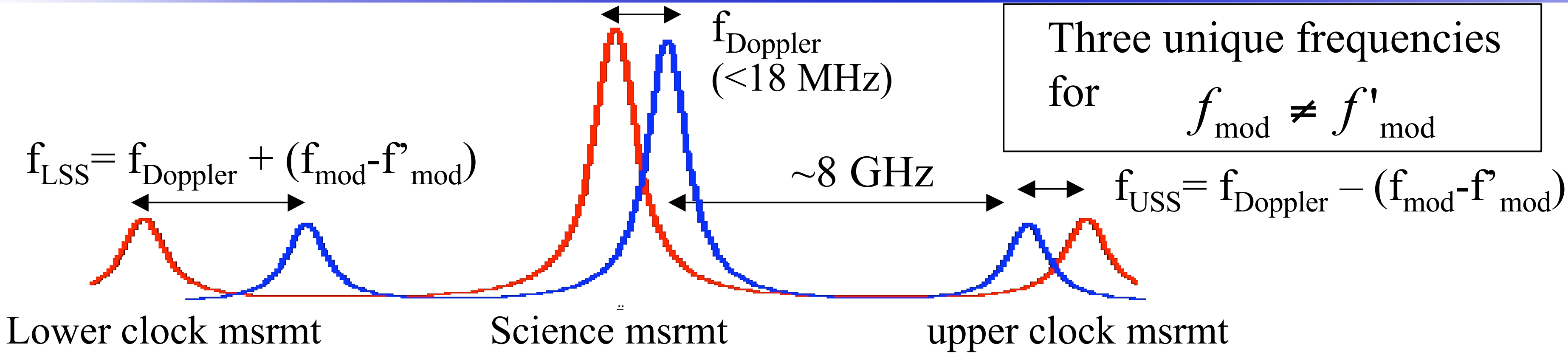
By measuring the clock noise we can either correct for it in post processing or consider steering the clock using:

$$\phi(t) = \phi(t') - \varepsilon(t')$$

where ε(t') is the measured phase error scaled by the ratio f_{het}/f_{mod}

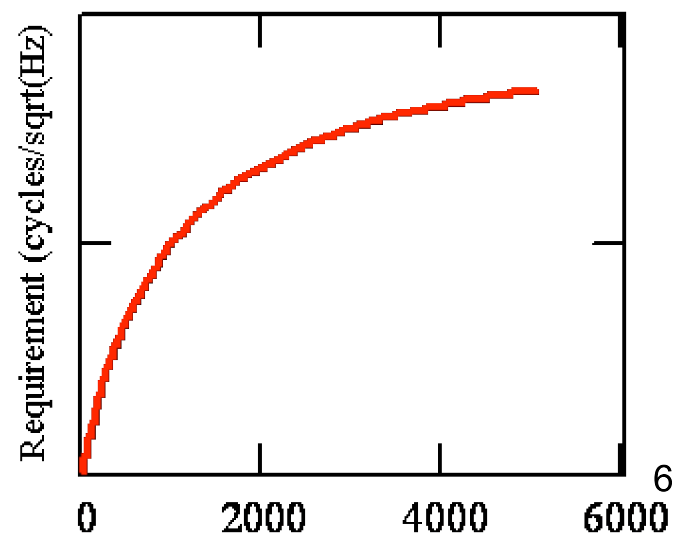
Sideband-sideband beat notes

Three unique frequencies for $f_{mod} \neq f'_{mod}$

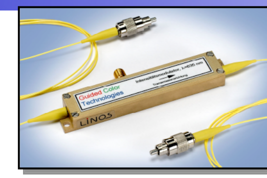


Using sideband-sideband beatnotes (instead of carrier-sideband) allows
high modulation frequency and low photoreceiver BW

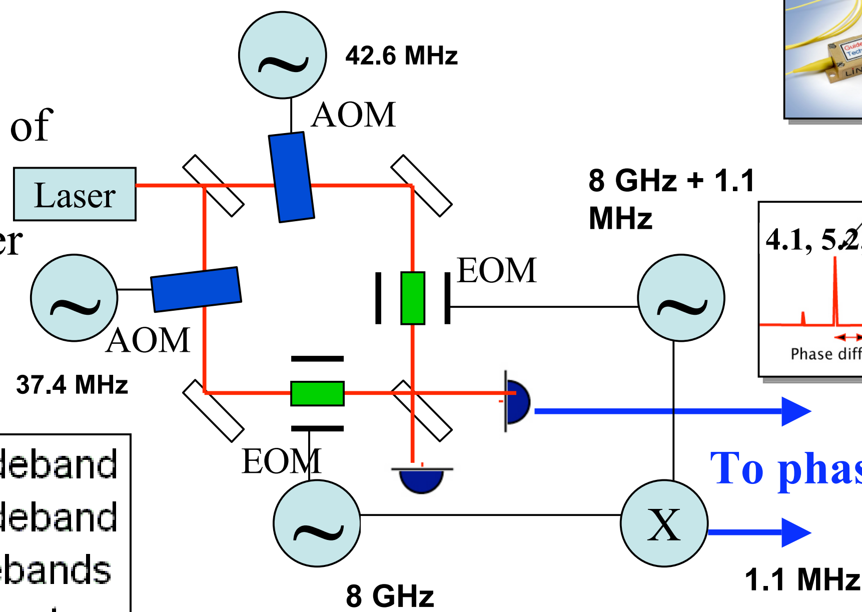
- Requirement on clock tone fidelity relaxes proportional to f_{mod}/f_{Het}
- Optical power required in the sidebands is proportional to $1/f_{mod}^2$, so we can run with ~1% power in sidebands instead of 15%

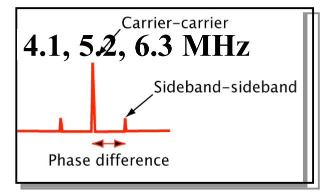


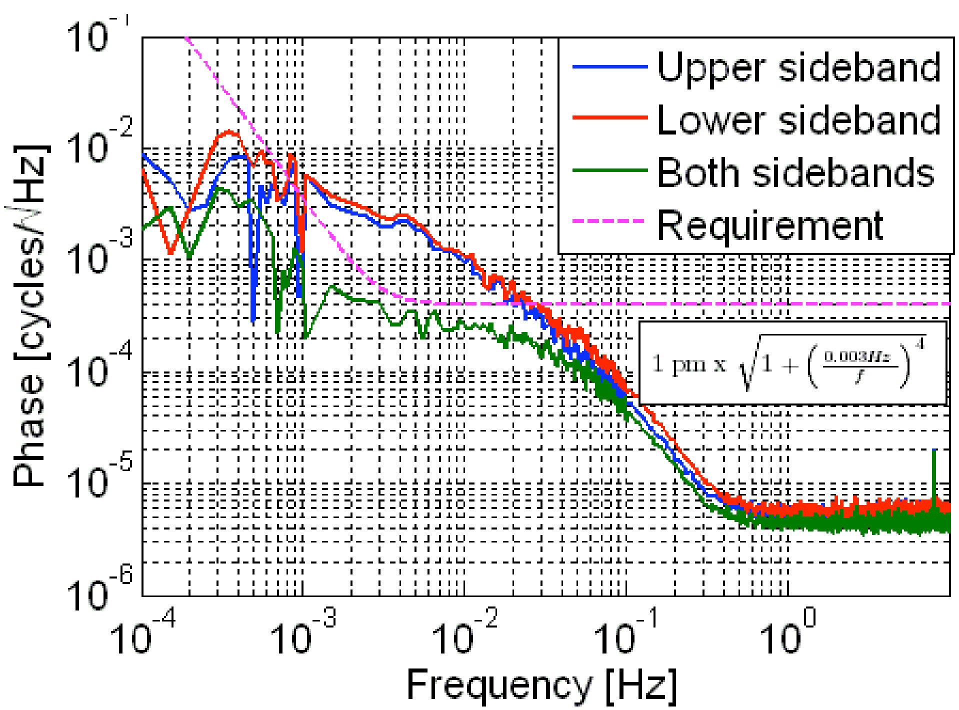
Relative phase stability of two EOMs



We tested the RF-optical-RF stability of two commercial fiber EOMS as components of the clock-noise transfer function:







- Modulators meet requirement over MBW with 8 GHz modulation
- Benefits of tracking upper and lower sidebands is clear
- Rise below 0.3 Hz not related to microwaves (AOMs?)

*See "Overview of the LISA Phasemeter," Shaddock – Friday at 10:50

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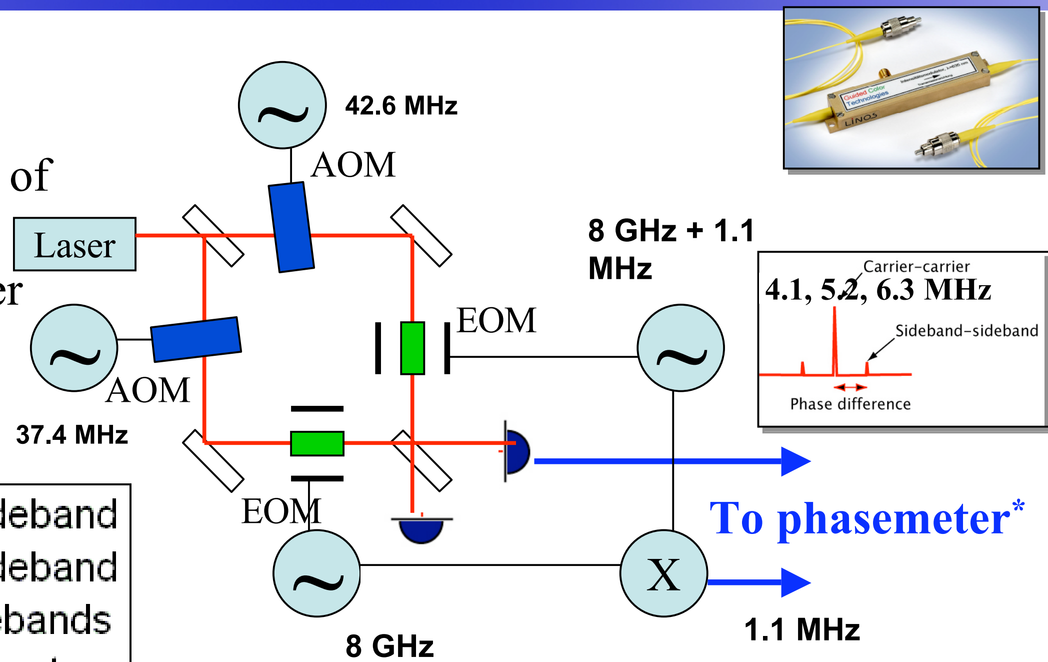

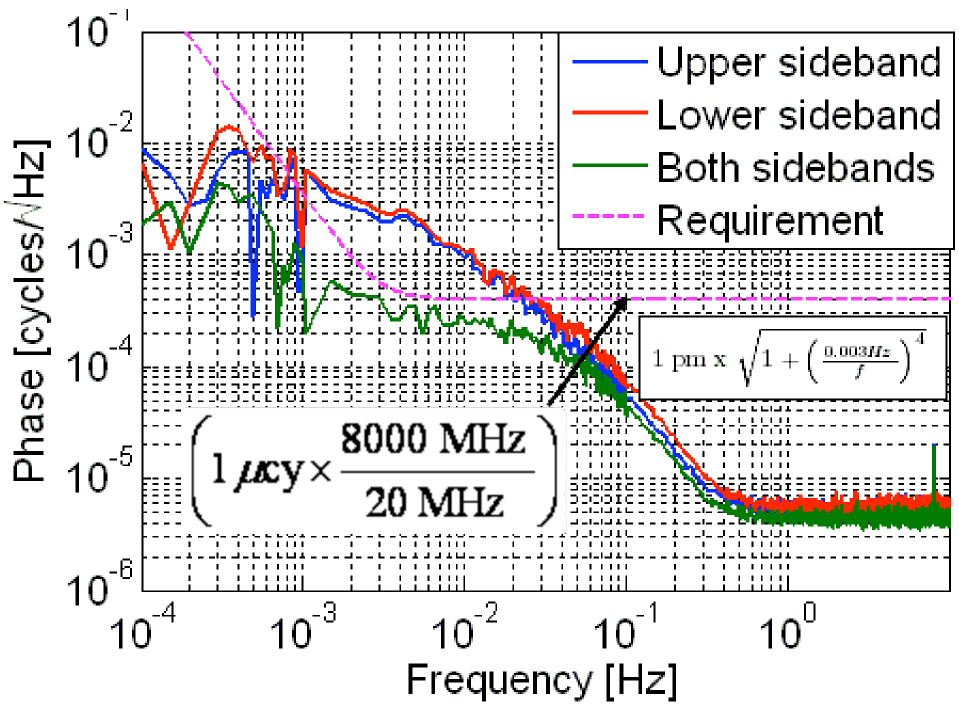

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Summary

- Clock noise must be measured and corrected for
- Use of the sideband-sideband beatnote eases requirements on the modulation as well as on the photoreceiver
- Higher modulation frequencies ease instrument performance requirements
- Measuring the upper and lower modulation sidebands makes the design less susceptible to, e.g., residual AM effects
- We have demonstrated that a commercial EOM meets this requirement
- We intend to demonstrate clock noise correction in our laboratory in the future